PRELIMINARY INVESTIGATION OF THE SEDIMEN-
TARY RECORD of 19th & 20th CENTURY BARK
BEETLE INFESTATION, ANTLER POND, NW CO

Preliminary Investigations of the Sedimentary Record of 19th and 20th Century Bark Beetle Infestation, Antler Pond, Northwestern Colorado

Final Report for A Research Joint Venture (USDA 28-JV7-949)

Between U.S. Forest Service & Northern Arizona University

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Submitted to:

31 March 1999

INTRODUCTION

The relationship between climate, vegetation type and disturbance (both fire and insect infestation) has attracted considerable interest from ecologists and paleoecologists, and more recently from land managers. Ecologists have long recognized that certain species (e.g., lodgepole pine, *Pinus contorta* var. *latifolia*) and plant communities (e.g., California chaparral, sequoia-mixed conifer forests) are adapted to fire (Lotan and Critchfield 1990; Keeley and Keeley 1988; Swetnam 1993), and that certain forest pest species, such as dwarf mistletoe, *Arceuthobium* sp., and spruce beetle, *Dendroctonus rufipennis* can have a significant impact on stand history and dynamics (Hawksworth et al. 1996; Schmid and Frye 1977).

Critical to our understanding of the characteristics of modern forests, and the concept of forest ecosystem health, is our understanding of the processes that have created the forests that we see today (Covington et al. 1995). In order to provide a comprehensive view on forest composition, a long-term perspective, with records on the order of centuries to millennia is necessary. For most purposes, long-term records are provided by one or more of the following: historical records and matched photographs, stand-age data, tree-rings, sediments accumulating in lakes and wetlands, or some combination. Of the above, the longest records will be obtained from tree rings and sediments.

Although a large body of literature has accumulated on the long-term history of fire in North American forests (see for example, Swetnam and Betancourt 1990; Swetnam 1993; Millspaugh and Whitlock 1995; Anderson and Smith 1997; Long et al. 1998), considerably less has been written regarding the long-term history of insect infestation. One such line of research involves utilizing variations in the width of tree-rings on living trees, comparing species that are susceptible to insect attack with those that are not susceptible. Swetnam and Lynch (1989) compared tree-ring chronologies from ten mixed conifer stands in the southern Rockies, and used these data to reconstruct western spruce budworm (*Choristoneura occidentalis*) outbreaks over the period of 1700 to 1983 AD.

A second line of research involves examining sediments from lakes near or within the areas affected by insect infestations. One example of this type of retrospective study is an attempt to provide an historical perspective on forest disturbance involving the "hemlock decline", a massive, widespread die-off of eastern hemlock (*Tsuga canadensis*), beginning ca. 4800 years ago. Using the occurrence of fossil microlepidopteran head capsules recovered from sediments, Anderson et al. (1986) detailed the history of microlepidopteran infestation in forests of northern Maine, covering the last ca. 10,000 years. They suggested that a microlepidopteran was responsible for the "hemlock decline". Recent evidence by Bhiry and Filion (1996) provided strong support for the association of defoliating insects and the "hemlock decline". The decline in hemlock is so striking (Allison et al. 1986) that its pollen profile is a precise time marker in sediments of eastern North America.

Pollen evidence was also used to track the "chestnut blight", a decline in American chestnut (*Castanea dentata*) caused by a fungal pathogen, *Cryphonectria parasitica* (Anderson 1974). The pathogen was introduced to New York City in 1904, and by 1915 it had wiped out much of the chestnut forests growing in southern Connecticut, New Jersey, southeastern New York, Pennsylvania, and northeastern Maryland. By 1925, nearly all mature chestnuts were dead in southern New England, southeastern New York, northern Vermont and eastern-central Pennsylvania. By the late 1940's, it had spread as far south as Alabama, Mississippi and

Tennessee. Using the decline in chestnut pollen extracted from sediments from lakes and ponds, Anderson (1974) was able to match the sedimentary record with the historical record of the chestnut decline.

In 1997, I proposed to use pollen evidence to investigate the recent history of spruce bark beetle infestation on the Medicine Bow-Routt National Forest in northwestern Colorado. The spruce beetle (*Dendroctonus rufipennis*) is the most serious insect pest of Engelmann spruce (Schmid and Frye 1977). Endemic spruce beetle populations are found in scattered live trees and fallen trees; during outbreaks, beetles can kill most canopy spruce over wide areas (Veblen et al. 1994). The beetle is restricted mostly to mature and overmature spruce, and epidemics have occurred throughout recorded history. A serious outbreak was recorded in northwestern Colorado during the 1880's (Sudworth 1900; Schmid and Frye 1977). A more recent infestation occurred in Colorado from ca. 1939 to 1951 AD, when beetles killed nearly six billion board feet of standing spruce, covering several 100,000 ha (Hinds et al. 1965; Schmid and Frye 1977; Alexander and Sheppard 1990; Baker and Veblen 1990).

My graduate students and I have been studying the vegetation and disturbance history of the Bear River Corridor, near the Flat Tops Wilderness Area, northwestern Colorado - an area surrounded by spruce forests killed during the 1940's spruce beetle infestation. Our previous analyses of a small lake ("N" Pond; Anderson, unpublished) and a large wetland (Dome Creek Meadow; Feiler et al. 1997) within the area showed substantial declines in pollen of spruce, which we believed corresponded to the historic outbreaks of spruce bark beetle and mass mortality of spruce. Our hypothesis suggests that as spruce trees are severely damaged or killed by the infestation, the pollen record would show either (1) a decline in pollen production (a decrease in the sedimentation of pollen in the lake sediment) or, (2) a decline in the pollen type in the overall pollen assemblage from sediment of that time period, corresponding to death of trees.

Although the most recent outbreaks are recorded in these records, earlier outbreaks are not recognized in these cores. The reason for this is due to a coarse pollen-sampling interval for our previous studies. Our original pollen-sampling interval varied from one sample per 100 years for "N" Pond to one sample per 380 years for Dome Creek Meadow. Clearly, if we are to achieve a record of disturbance on the decadal to centennial time-scales, our sampling interval must be at the decadal scale (one sample every 10 years or less).

The sediments from Antler Pond, nearby to "N" Pond and Dome Creek Meadow, have allowed us to investigate the most recent sediments in more detail. Antler Pond is a small kettle lake, located on top of a large lateral moraine adjacent to the Bear River. Its location at 3128 m (10,260 ft) elevation places it within the spruce-fir forest of the Medicine Bow-Routt National Forest, and within the spruce beetle outbreak of the 1940's. The pond is surrounded by mature, dead spruce, with an understory of young spruce. It is within 20 km of the Trappers and Marvine Lakes study sites of Veblen et al. (1991a) and Veblen et al. (1994). The sediments of the pond are laminated, indistinctly so in the upper portion, with more distinct laminations below. Thus, the record from Antler Pond has allowed us to obtain sub-decadal scale resolution.

The ideal lake for detailed sampling is one in which the annual increment of sediment is deposited as a "varve" - a annual couplet of two layers (Saarnisto 1986). One layer of the couplet corresponds to the sediment deposited during summer and the other to that in winter (in much the same way as conifer trees grow an early growing season ring, followed by a late

growing season ring). Lakes with varves are extremely rare. Varved sediments can preserve an annual record of pollen for a particular year. Varves are preserved because the environment at the bottom of the lake is generally too hostile (lacking oxygen) to support burrowing fauna which inhabit the sediments of other lakes, and that mix the sediment during their burrowing activities. For Antler Pond, the layering in the upper sediments is slightly disturbed due to movement of evolving gas from older sediments below. However, the occurrence of remnant banding in the sediments argues for only moderate mixing. In other words, the upper sediments of Antler Lake probably preserve a signal that is quasi-annual, with two to three years of sediment being mixed into the same sample. Even so, the sediments of Antler Pond have proven to be more than adequate to preserve a detailed pollen record of the periodic disturbance of the spruce forest over the last few centuries.

METHODS

Sediments from Antler Pond, Colorado (Orno Peak 7.5' USGS Quadrangle) were obtained prior to the initiation of this project, in the summer of 1996. We obtained short cores (ca. 0.75 m long) of the upper sediment of the pond from a small floating platform. The frozen cores were taken using a modified hollow box corer (Wright 1991), constructed in the shape of a wedge. A combination of ethyl alcohol and dry ice were placed in the box, lowered into the sediments, and allowed to remain there until a thick (ca. 1-2 cm) crust of undisturbed lake sediment froze onto the outside of the box. Upon retrieval of the corer at the lake surface, the slabs of sediment were chipped off of the box corer, wrapped in plastic and foil, and stored in coolers filled with dry ice.

Laboratory research and analysis consisted of three phases: (1) mapping and photographing the sediments from Antler Pond, (2) subsampling of sediments for pollen analysis, and (3) subsampling of the core for radiometric dating.

Mapping and Core Photography. In order to analyze the sediments and to identify if they were semi-annual, I prepared cross-sections of one of the frozen cores from Antler Pond. Using a bandsaw in a cold room, I cut the frozen slab lengthwise to expose a fresh surface (Ribbon I; Figure 1). This surface was photographed in the cold room, keeping the sediments frozen, to identify and document the sections of the core that were laminated, partially laminated, and non-laminated. Photographs of the entire length of Antler Pond Core 9A were obtained, measuring a total of ca. 50 cm of core. The Ribbon I section of the core was archived for future analyses.

Pollen Analysis. A second Ribbon (II) was cut from the core slab and subsampled for pollen analysis. Ribbon II measured ca. 7.5 mm thick, 25.0 mm deep, and 30 cm long. Pollen subsamples measured 5 mm in length over the top 20 cm of core. Thus, I isolated 40 pollen samples which cover the top 20 cm of core 9A. The volume of each of the pollen subsamples was then 0.9375 cm^3 (0.5 cm X 0.75 cm X 2.5 cm). Based upon assumed sediment accumulation rates, I initially assumed that each one of these samples represented from 5 to 10 years of deposition.

For each of the pollen subsamples, 0.5 cc of sediment was measured into a graduated cup, and was subjected to a modified Faegri & Iversen (1989) pollen process. Because samples from the upper portion of the core are less compacted than those below, and included proportionally greater amounts of water, the sample was centrifuged and the water removed.

The resulting volume of sediment was noted. A single *Lycopodium* tracer tablet (= 12,542 grains / tablet) was added to each for subsequent calculation of pollen concentration. Remaining processing steps included suspension in 10% KOH (to disaggregate organics), 10% HCl (to dissolve any carbonates), HF (to dissolve silicates), and acetolysis solution (to digest organics). The resulting pollen residue was dehydrated with alcohol, stained with Safranin "O", and suspended in silicone oil.

Pollen assemblages were placed on a microscope slide, and grains were identified with a Leitz Laborlux microscope at 400X. Grains were compared to species in the Laboratory of Paleoecology reference collection, and published keys. The pollen sum of non-aquatic grains for the 40 samples averaged 330 grains (range = 289 to 403 grains). For each level in the core, pollen percentages and influxes were calculated. Pollen percentages were determined for each taxon by dividing the number of grains for that taxon by the total pollen sum. For calculation of the pollen influx for each level, we multiplied the pollen concentration value for each taxon by the sedimentation rate, as determined by the ^{210}Pb dating. Pollen influx rates are given as number of pollen grains deposited on a cm^2 surface per year (grains/cm^2/yr). Pollen data were plotted using the Tilia-Graph program developed by Dr. Eric Grimm, Illinois State Museum.

Radiometric Dating. Since radiocarbon dating is problematic for sediments deposited during the most recent 4-5 centuries (Stuiver 1978), and the standard error associated with a radiocarbon date is often on the order of plus or minus several decades, I chose to date the sediments using both ^{210}Pb and ^{137}Cs chronologies. ^{210}Pb is suitable for dating within the range of the most recent 1-150 years, since its half-life is 22.26 $\pm$ 0.22 years (Olsson 1986; Blais et al. 1995). For precision of the most recent sediments, ^{137}Cs can be used. ^{137}Cs has a half-life of ca. 30 years, and was produced in great abundance during nuclear testing in the atmosphere, beginning in 1945 (Olsson 1986). The first pronounced increase of ^{137}Cs in the atmosphere occurred in 1954, with a maximum occurring in 1963-1964. By 1965, the activity was about one-third of that in 1963.

For the radiometric dating samples, I cut a third section of the frozen core (Ribbon III), and cut it into individual rectangles with dimensions of 0.5 cm X 0.75 cm X 5.0 cm (volume ca. 1.875 cm^3). The actual dating of the sediment column was accomplished in the laboratory of Dr. Richard Ku, Department of Geosciences, University of Southern California.

RESULTS

The sediments are indistinctly laminated, especially in the upper portion of the record (Figure 1), but more distinctly laminated below. During coring, we noticed gas bubbles rising to the surface of the lake. We assumed that the gas originated from the lake sediments below. Consequently, the layering in the upper sediments is somewhat disturbed probably due to this upward gas movement. However, the occurrence of remnant banding in the sediments argues for only moderate mixing. I now believe that the upper sediments of Antler Pond probably preserve a pollen signal that is quasi-annual, with two to three years of sediment being mixed into the same sample. Most of the top 20 cm is partially laminated. Laminations are more distinct below 34 cm, but the pollen assemblages for this portion of the record were not analyzed.

Sediment chronology was determined by analysis of 25 sediment samples from Ribbon III, in 1-cm increments (Table 1). Dr. Ku analyzed the activity (disintegrations / minute / gram = dpm/g) for ^{210}Pb, ^{214}Pb, ^{226}Ra and ^{137}Cs. The excess ^{210}Pb activity was calculated by

subtracting ^{214}Pb activity from the total ^{210}Pb activity for each sample (Table 1). Below 14 cm there is no measurable ^{210}Pb. Below 17 cm there is no measurable ^{137}Cs. Based upon the slope of the straight line in the ^{210}Pb plot (Figure 2) the average sedimentation rate for the top 14 cm of the core is 0.16 cm/yr. The fallout of ^{137}Cs peaks around 4.5 cm. If we take this level as being close to the year 1964 AD, the sedimentation rate for the top 4.5 cm based upon the ^{137}Cs stratigraphy (= 0.14 cm/yr) is comparable to the ^{210}Pb rate.

The two pollen diagrams (Figure 3, pollen percentage diagram; Figure 4, pollen influx diagram) show the pollen data for the Antler Pond record graphed by depth and age. Note the timescale, which is in calendar years before 1996 AD. Of particular interest are the curves for spruce (*Picea*) and fir (*Abies*). Engelmann spruce (*P. engelmannii*) and subalpine fir (*A. lasiocarpa*) and the two dominant tree species within the subalpine forest of the region. The diagram can be broken into four distinct zones. Below ca. 140 mm depth (ca. 1908 AD), *Picea* percentages are low but increasing, while *Abies* percentages are generally even. From ca. 140 mm to ca. 75 mm depth (ca. 1949 AD) *Picea* percentages fluctuate greatly. *Abies* pollen percentages are generally lower, although some fluctuations occur. From ca. 75 mm to ca. 50 mm depth (ca. 1965 AD), *Picea* pollen percentages remain stable but *Abies* percentages begin to increase. Lastly, from ca. 50 mm depth to the top of the core (1996 AD), *Picea* percentages decline, but *Abies* percentages increase.

The pollen influx record (Figure 4) is very similar to the pollen percentage record (Figure 3), but differs in some of the details. However, the record from pollen influx is preferred over the pollen percentage record because of inherent biases in percentage data. For example, since each taxon's percentage is a fraction of the whole, variations in one taxon affect the percentage of all of the other taxa (Davis 1963). However, since each pollen taxons influx rate is determined individually, variations of one taxon do not affect the influx rate of other taxa.

DISCUSSION

A basic tenet of fossil pollen analysis involves the relationship between fossil pollen assemblages and the forest-species assemblages that produced them. As stated in the introduction, a primary hypothesis of this research has been that changes in the pollen production (thus, influx to the sediments) should reflect, in some fashion, the changes in the number of pollen-producing trees on the landscape. If little mixing exists in the sedimentary record, as witnessed by laminated - or nearly laminated - sediments, then our ability to resolve the details of forest disturbance history over the course of time is enhanced. Though the sediments from Antler Pond are only partially laminated, several indicators suggest that a sub-decadal record is mostly preserved. First, photographs of the sediments (Figure 1) record semi-distinct bands of dark and light sediment, which are probably the remnants of seasonal sediment deposition within the lake. Second, radiometric ages of the sediments, especially the ^{137}Cs record, show sharp transitions between individual core levels. For instance, a distinct peak in ^{137}Cs occurs at ca. 4.5 cm in the record, corresponding to the height of atmospheric nuclear testing in 1963-64. Significant mixing of the sediments, either by biological or physical means, would be expected to blur the isotopic signature of the record, which it has not. Third, many of the microfossil types in the pollen record have distinct boundaries between levels (e.g., the increase in *Isoetes* between 102.5 and 97.5 mm; the disappearance of *Botryococcus* between 42.5 and 37.5 mm; the detail in the Picea record). For these reasons, I feel confident in interpreting the record as one with sub-decadal resolution.

My original intention was to investigate whether the sediments from Antler Pond would preserve a record of the effects of large-scale forest disturbance. Our initial research from other sedimentary basins nearby suggested that widespread episodic outbreaks of spruce bark beetle infestation could be detected in the sedimentary record ("N" Pond [Anderson, unpublished] and Dome Creek Meadow [Feiler et al. 1997]). A 20th century outbreak affected large areas of northwestern Colorado in the 1940's (Schmid and Frye 1977). Outbreaks of the bark beetle, occurring in the subalpine zone, appear to be triggered by blowdowns or accumulation from logging slash (Hinds et al. 1965; Schmid and Frye 1977). In 1939, an extensive blowdown on the White River Plateau allowed populations of the beetle to reach outbreak levels. The infestation raged throughout the 1940's within the area, and had subsided by 1952 (Massey and Wygant 1954; Veblen et al. 1991a). Estimates place the affected area on the White River Plateau, including the area surrounding Antler Pond, at ca. 290,000 ha (Hinds et al. 1965; Cahill 1977; Veblen et al. 1991a). The record from Antler Pond has provided an opportunity to examine potential successional changes in the subalpine forest in detail.

Examination of the pollen percentage and pollen influx diagrams show clear evidence of impact within the subalpine forests surrounding Alpine Pond. The radiometric dating is critical in placing the events in a chronological perspective. The impact of the beetle infestation is shown by a decline in pollen influx and percentages of spruce, centered around 80 mm depth in the core. This depth corresponds to radiometric ages placing the interval in the 1940's. A protracted (three sample) decline in spruce is followed by a return to higher spruce pollen influx and percentages values that last throughout the 1950's, but is also accompanied by an increase in the influx of fir pollen. From that time until the present, fir pollen influx continues to increase while spruce pollen declines somewhat.

The pattern displayed in the pollen record is precisely the pattern deduced from recent analyses of stand composition in the Trappers Lakes area of the White River Plateau, ca. 10 km to the southwest of Antler Pond. Veblen et al. (1991) examined the forest age structure of three stands (Trappers Lake, Lily Pond, Ripple Creek) near Trappers Lake, each of which had been severely impacted by the 1940's spruce bark beetle outbreak. In each case, tree composition of the stands had been shifted dramatically from dominance by Engelmann spruce prior to the outbreak, to subalpine fir subsequent to the outbreak. At the Trappers Lake site, basal areas for subalpine fir and engelmann spruce were 13.5 and 2.5 m^2/ha, respectively. An identical pattern was found at the Lily Pond (20.5 and 11.6 m^2/ha) and Ripple Creek (30.3 and 6.4 m^2/ha) study sites (Table 2 of Veblen et al. 1991a). Lodgepole pine (*Pinus contorta*) trees were also impacted by the infestation at the Trappers Lake site, with standing dead and live tree basal areas at 14.1 and 3.9 m^2/ha, respectively. This may be reflected by a decline in the influx of "large pine" pollen contemporaneous with the spruce pollen decline (Figure 3).

Even more striking were data collected from tree-rings of surviving trees forty years after the outbreak. Death of the canopy trees apparently did not lead to a major recruitment event for Engelmann spruce. Instead, growth-ring thickness increased substantially throughout the 1950's and into the 1960's, demonstrating a pattern of growth release of surviving trees not impacted by the infestation (Figure 5 of Veblen et al. 1991a). Control sites did not show the same pattern of release during the 1950's, indicating that the release pattern was a direct result of the beetle-kill.

I interpret the short-term increase in spruce pollen influx subsequent to the beetle outbreak as the result of release of sub-dominant and sub-canopy spruce trees. Similarly, the

long-term increase in fir pollen influx to the sediments reflects the shift to fir tree dominance in the local forest composition. I conclude that the pollen record is consistent with the forest composition model developed by Veblen et al. (1991a) for areas on the White River Plateau that were severely impacted by beetle infestation during the 1940's.

It is tempting to interpret earlier events as revealed in the pollen diagrams as a function of additional forest disturbance events. Although the Antler Pond pollen record presently extends back in time no further than the 1870's, it is possible that a general record of an earlier spruce bark beetle infestation is preserved. Early foresters (Sudworth 1900; Hopkins 1909) reported extensive dead, standing Engelmann spruce on both the Grand Mesa and White River Plateau, which they assumed dated from an infestation in the 19th century. Again, research by Veblen et al. (1991a) confirmed growth releases in both spruce and fir occurred in the middle to latter 19th century. The pollen record shows low spruce pollen influx near the bottom of the core (ca. 190 mm depth, corresponding to ca. 1875 AD), followed by sustained pollen influx of fir, which lasted from the 1880's to the early 1900's. However, confirmation of this series of events must wait until sediments deeper in the core can be analyzed, providing a possible reconstruction of antecedent conditions for comparison with the historical record.

The record for most of the first half of the 20th century, from ca. 145 mm to ca. 80 mm depth, shows a variable pattern of spruce pollen percentages and influx, associated with higher influx of the "large pine" pollen. It is tempting to ascribe this to the occurrence of fires within the local vicinity (see Baker and Veblen 1990), which might favor the establishment and growth of lodgepole pine. Analyis of charcoal particle from the sediments may assist in interpretation of this part of the record. However, charcoal analysis was not conducted for the preliminary assessment of the Antler Pond record.

CONCLUSIONS

Several direct conclusions can be drawn from these preliminary data. First, the uppermost sediments of Antler Pond contain a sub-decadal record of pollen influx from the subalpine forest of the White River Plateau. Sediment accumulation in the upper 20 cm is ca. 1.6 mm/yr. Since each pollen sample consists of 5 mm of sediment length of core 9A, each pollen sample incorporates about three years of accumulated sediment. Though the level of resolution of this partly laminated core is not equal to fully-laminated, "varved" sediments, it is more than adequate to resolve the disturbance and forest succession events of the past century near the pond, and over a wider area of the White River Plateau.

Second, the pollen record is consistent with other data (Veblen et al. 1991a; Veblen et al. 1991b; Veblen et al. 1994) which have shown that the bark beetle preferentially killed larger Engelmann spruce trees during the outbreak of the 1940's, allowing a release of sub-dominant trees in the subalpine forest. In addition, the pollen data provide corroboratory evidence of the shift in dominance to subalpine fir within these high elevation forests during the latter half of the 20th century. Though the presently analyzed portion of the Antler Pond core 9A record does not stretch back beyond the 1870's, there is indication that an older infestation is recorded in the sediments as well.

Third, radiometric dating is important for resolving the timing of the changes seen in the pollen record. ^{210}Pb and ^{137}Cs dating techniques are invaluable for determining the chronology of events during the most recent 150 years. Beyond the range of these two

radiometric techniques, ^{14}C dating is important. Unfortunately, the Antler Pond sediments are no longer annually laminated, so additional research on this record will rely on building an accurate chronology with radiocarbon dating. Sediment laminations are better preserved in sections of the core below the top 20 cm (Figure 1), and it is possible that a nearly annual record may be obtained for selected sections of the core at greater depth.

Additional research should be undertaken on this record to determine the impact of spruce bark beetle infestation on subalpine forests that existed on the White River Plateau in earlier time periods. Such a study could use the information gathered here as a model for successional changes within the forest. In addition, charcoal analysis of the Antler Pond sediments should be undertaken in order to obtain a more complete picture of forest disturbance within the region. Comparison of these data to independently-derived climate records could demonstrate any link to specific climatic regimes of the past, and perhaps aid in developing a predictive model for future events in a time of rapidly changing climate.

ACKNOWLEDGEMENTS

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Figure 1. Cross sections of two segments of the frozen Antler Pond core 9A. Segment 0-9 cm depth (left) and segment 31-40 cm depth (right).
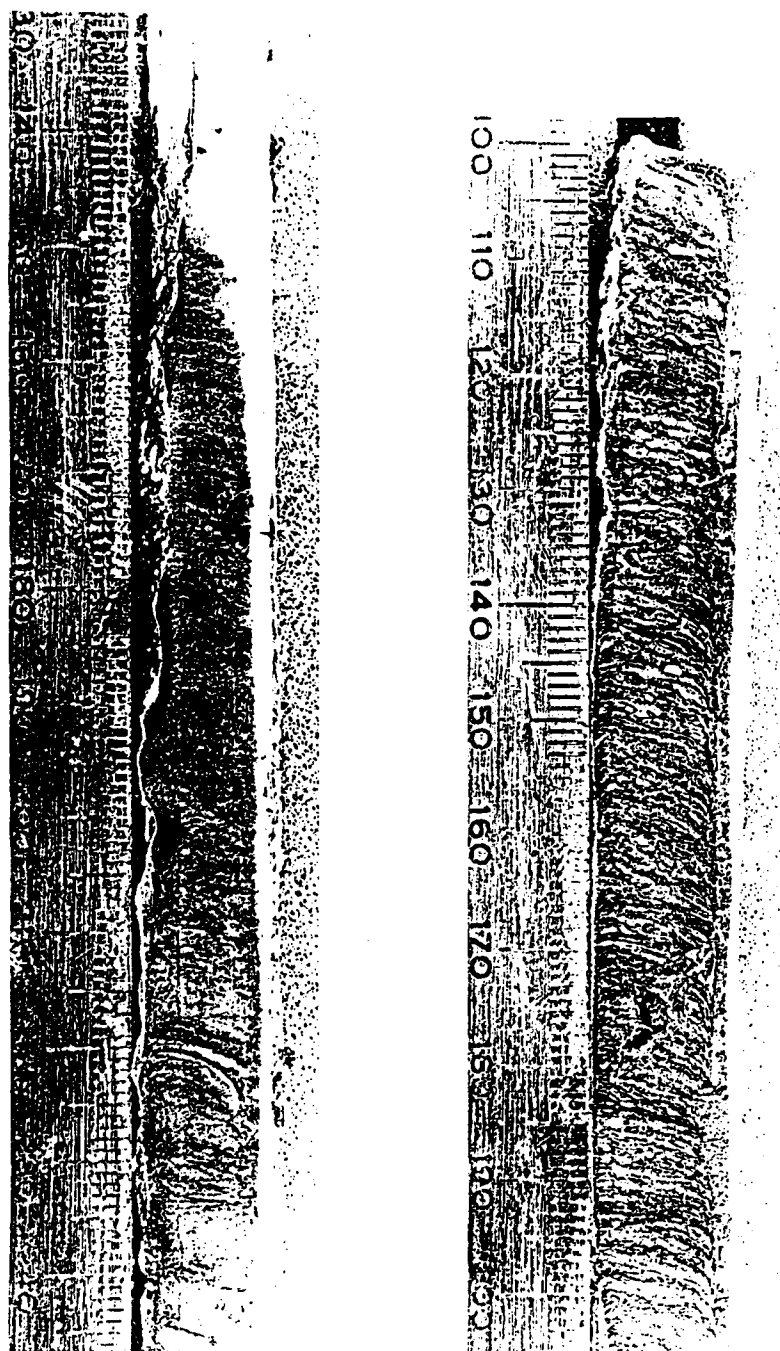
Antler Pond, Core 9B

$y = 85.748 * e^{(-0.19637x)}$ $R^2 = 0.9442$
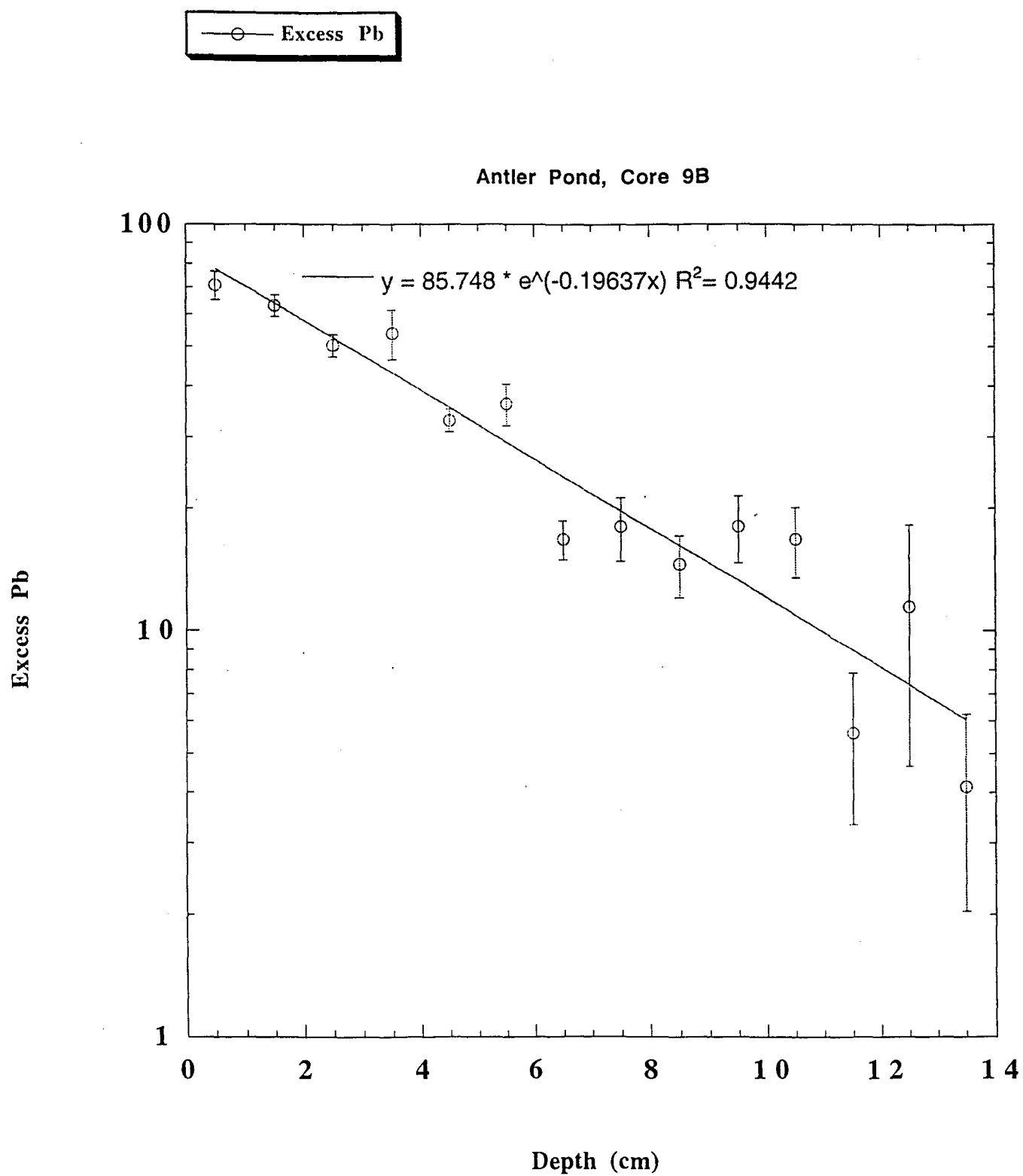
Excess Pb

Depth (cm)

Figure 3. Summary pollen percentage diagram for Antler Pond core 9A.
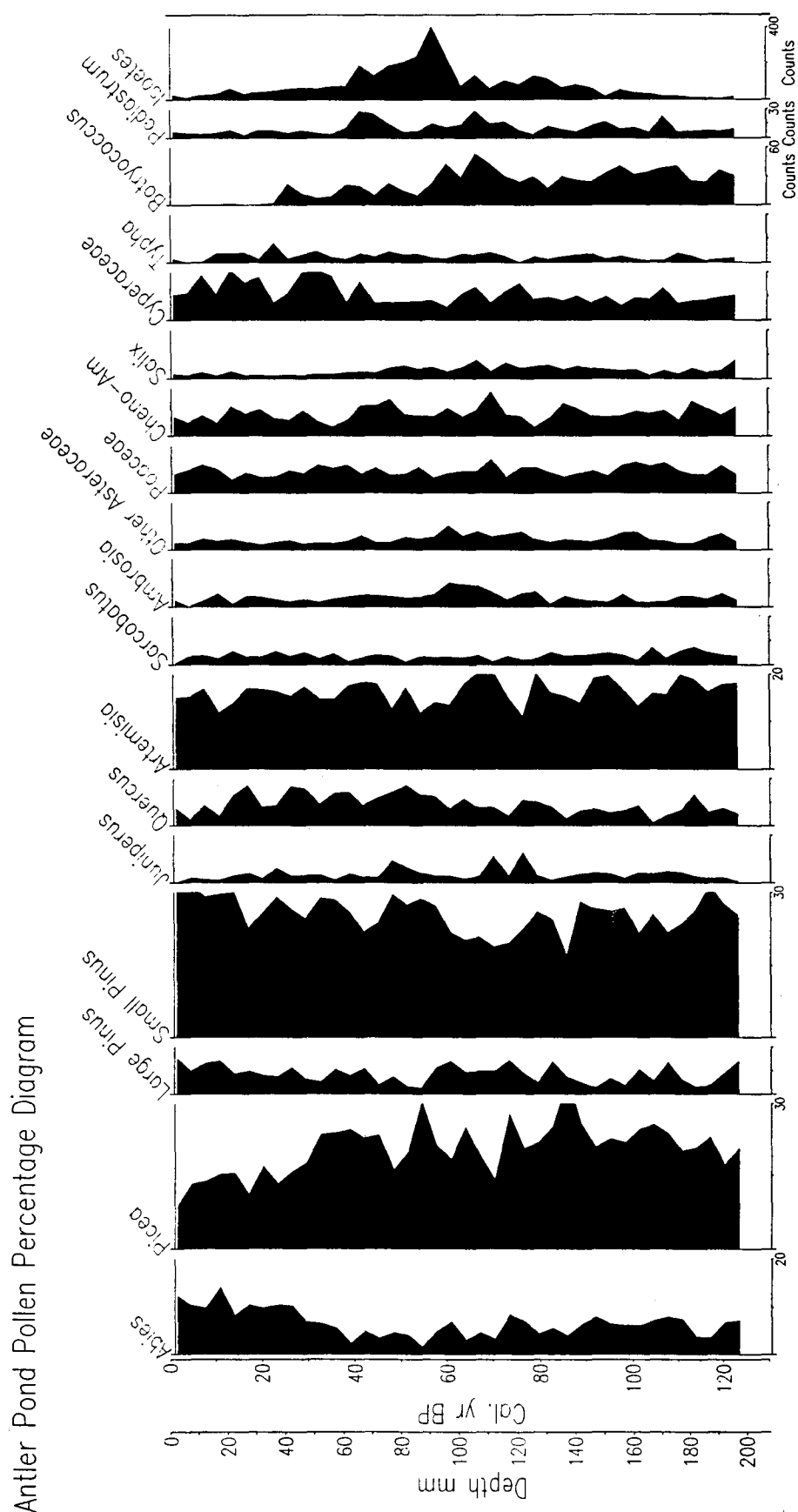
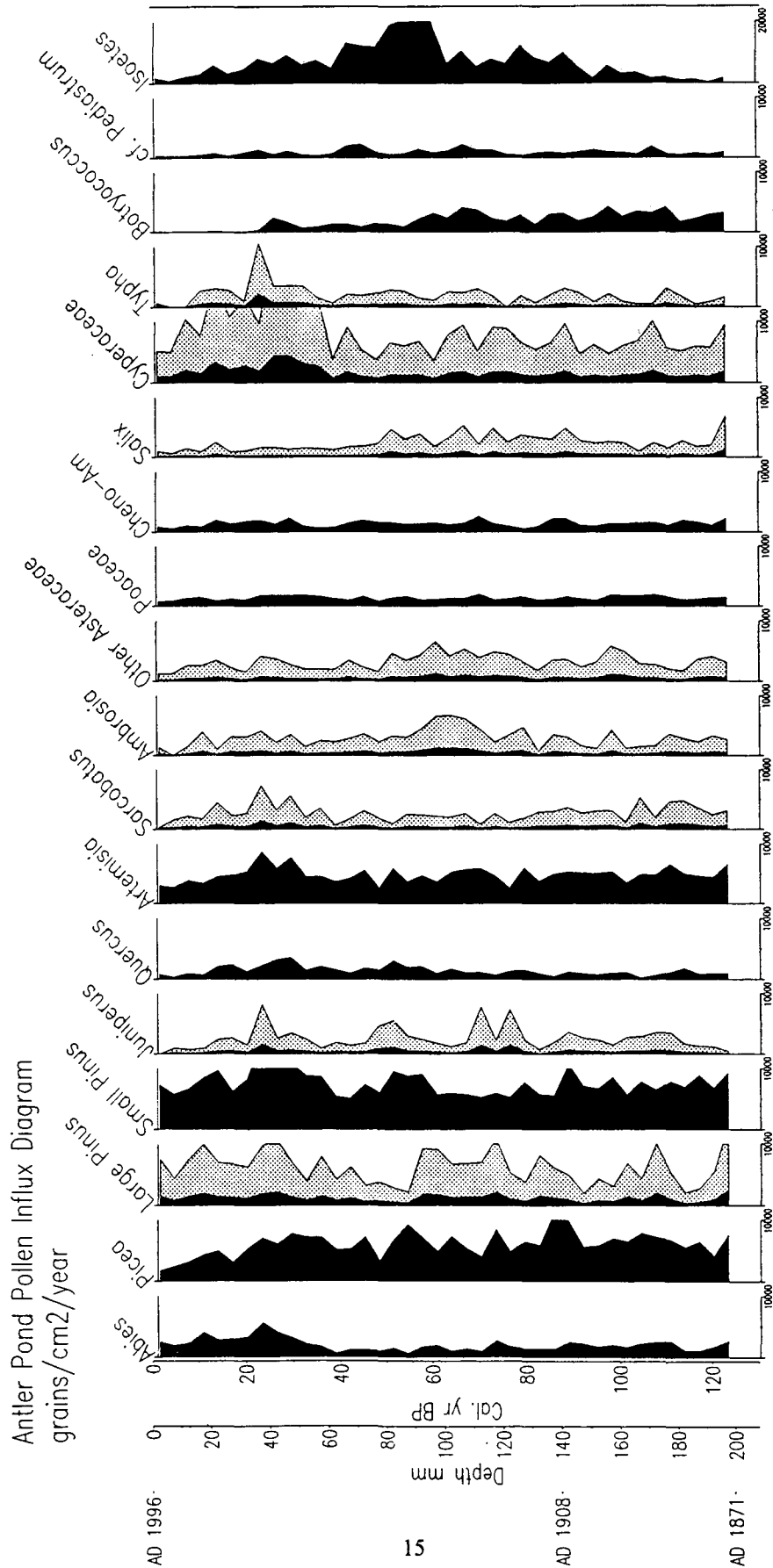Figure 4. Summary pollen influx diagram for Antler Pond core 9A.

Table 1. Radioisotope results of radiometric dating - ^{210}Pb and ^{137}Cs - from Antler Pond core 9A.

Pb-210 results for core 9B, Antler Pond

Sample No.	Depth (cm)	Pb-210 (dpm/g)	Pb-214 (dpm/g)	Ra-226 (dpm/g)	Cs-137 (dpm/g)	Excess Pb-210 (dpm/g)*
AP-9B-1	0-1	73.12 ± 5.27	2.25 ± 2.30	8.00 ± 4.46	10.99 ± 0.69	70.87 ± 5.75
AP-9B-2	1-2	63.16 ± 3.95	0.00 ± 0.00	0.00 ± 0.00	20.91 ± 1.09	63.16 ± 3.95
AP-9B-3	2-3	52.44 ± 2.95	2.16 ± 1.08	0.00 ± 0.00	22.81 ± 0.84	50.28 ± 3.14
AP-9B-4	3-4	58.48 ± 6.96	4.53 ± 2.97	0.00 ± 0.00	42.87 ± 1.55	53.95 ± 7.57
AP-9B-5	4-5	36.69 ± 1.95	3.70 ± 0.81	2.90 ± 1.63	82.17 ± 1.04	32.99 ± 2.11
AP-9B-6	5-6	38.23 ± 3.75	2.00 ± 1.92	0.00 ± 0.00	25.96 ± 0.89	36.23 ± 4.21
AP-9B-7	6-7	20.46 ± 1.73	3.70 ± 0.68	6.64 ± 2.96	6.67 ± 0.49	16.76 ± 1.86
AP-9B-8	7-8	22.03 ± 2.70	4.05 ± 1.68	4.30 ± 2.01	5.91 ± 0.62	17.98 ± 3.18
AP-9B-9	8-9	18.94 ± 2.35	4.40 ± 0.88	3.54 ± 2.91	4.40 ± 0.49	14.54 ± 2.51
AP-9B-10	9-10	21.88 ± 2.89	3.83 ± 1.73	6.92 ± 3.13	4.56 ± 0.59	18.05 ± 3.37
AP-9B-11	10-11	18.99 ± 3.17	2.21 ± 0.92	4.28 ± 1.83	4.13 ± 0.64	16.78 ± 3.30
AP-9B-12	11-12	9.61 ± 1.95	4.01 ± 1.16	7.66 ± 3.13	3.08 ± 0.51	5.60 ± 2.27
AP-9B-13	12-13	11.42 ± 6.77	0.00 ± 0.00	0.00 ± 0.00	1.78 ± 0.55	11.42 ± 6.77
AP-9B-14	13-14	7.82 ± 1.88	3.68 ± 0.94	2.40 ± 2.12	2.75 ± 0.54	4.14 ± 2.10
AP-9B-15	14-15	3.03 ± 3.85	1.37 ± 0.88	1.70 ± 1.66	1.33 ± 0.31	1.66 ± 3.95
AP-9B-16	15-16	4.20 ± 1.70	2.48 ± 0.99	7.81 ± 3.90	0.59 ± 0.31	1.72 ± 1.97
AP-9B-17	16-17	3.51 ± 0.78	2.44 ± 0.48	7.93 ± 2.60	0.98 ± 0.28	1.07 ± 0.92
AP-9B-18	17-18	4.28 ± 0.79	3.70 ± 0.60	-0.01 ± 0.03	na ± na	0.58 ± 0.99
AP-9B-19	18-19	4.95 ± 1.43	2.08 ± 0.87	9.90 ± 3.00	na ± na	2.87 ± 1.67
AP-9B-20	19-20	4.22 ± 1.05	1.78 ± 0.80	12.57 ± 3.25	na ± na	2.44 ± 1.32
AP-9B-21	20-21	4.26 ± 1.21	3.21 ± 0.51	3.57 ± 1.62	na ± na	1.05 ± 1.31
AP-9B-22	21-22	3.89 ± 1.20	2.74 ± 0.86	6.98 ± 4.03	na ± na	1.15 ± 1.48
AP-9B-23	22-23	3.85 ± 1.45	3.80 ± 0.80	-1.99 ± 2.50	na ± na	0.05 ± 1.66
AP-9B-24	23-24	3.29 ± 1.06	4.29 ± 1.15	6.19 ± 3.98	na ± na	-1.00 ± 1.56
AP-9B-25	24-25	3.20 ± 0.69	2.57 ± 0.66	-0.57 ± 0.95	na ± na	0.63 ± 0.95

Excess Pb-210 is calculated by substracting Pb-214 activity from total Pb-210 activity for each sample
All activities are as of June 1, 1998
Below depth 17cm, there is no measurable Cs-137.